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Effect of Random Thermal Spikes on Stirling Convertor Heater Head Reliability

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December 2004

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Onboard radioisotope power systems being developed to support future NASA exploration missions require reliable design lifetimes of up to 14 years and beyond. The structurally critical heater head of the high-efficiency developmental Stirling power convertor has undergone extensive computational analysis of operating temperatures (up to 650 °C), stresses, and creep resistance of the thin-walled Inconel 718 bill of material. Additionally assessment of the effect of uncertainties in the creep behavior of the thin-walled heater head, the variation in the manufactured thickness, variation in control temperature, and variation in pressure on the durability and reliability were performed. However, it is possible for the heater head to experience rare incidences of random temperature spikes (excursions) of short duration. These incidences could occur randomly with random magnitude and duration during the desired mission life. These rare incidences could affect the creep strain rate and therefore the life. The paper accounts for these uncertainties and includes the effect of such rare incidences, random in nature, on the reliability. The sensitivities of variables affecting the reliability are quantified and guidelines developed to improve the reliability are outlined. Furthermore, the quantified reliability is being verified with test data from the accelerated benchmark tests being conducted at the NASA Glenn Research Center.

I. Introduction

Stirling Radioisotope Generator (SRG) being developed by the NASA Glenn Research Center (GRC), the Department of Energy (DOE), Lockheed Martin of Valley Forge, Pennsylvania, and Stirling Technology Company of Kennewick, Washington under NASA's Project Prometheus is considered to be a potential candidate for the possible use on future NASA exploration missions. Prime design requirement of the SRG is to ensure its efficient and reliable performance during an entire mission without maintenance and repair. These candidate missions are typically long lived, lasting for up to 14 years. Therefore the assessment of reliability of SRG is very critical to achieve a successful mission. Stirling convertor is the most critical subsystem of SRG that is responsible to convert the thermal energy from radioisotope material to electric power. The heater head is one of the most critical components of the Stirling convertor. It conducts heat from the general-purpose heat source (GPHS) module of the Radioisotope Power System (RPS) and supplies it to the convertor for the generation of electricity.

A normal heater head design process would involve performing feasible component tests to validate the design in order to assure reliable durability along with ample functional performance before long-term structural systems can be accepted for use. However, due to technical and practical limitations, it is not possible to run full-duration, long-term tests that would simulate the actual operational conditions. Additionally, it is difficult to capture the effects of uncertainties in the material behavior, fabrication, manufacturing process, operational load conditions, etc. in a limited number of tests. Current design approaches involve computer simulations or virtual experiments, validated with the limited test data, under different design and operating conditions to understand the behavior of components and aid quantification of the long-term behavior and estimate reliability. Computer simulations enable studying the effect of design changes and the impact of variations in critical design variables on component performance in a shorter time at lower cost and without performing full-up test. Also, computer simulations can be validated with the available test data.

The structurally critical cylindrical heater head is made of thin section wrought Inconel 718 and must operate continuously at temperatures as high as 650 °C. Creep resistance is the prime-durability limitation. The design variables governing the performance and life of the heater head will have uncertainties from different sources such as fabrication (geometry), environmental loads (pressure and temperature) and long-term creep behavior of the material (Inconel 718).

A reliability assessment of the heater head, validated using limited test data, that include the effect of uncertainties in the design variables has already been performed and a long term durability with high reliability was demonstrated (Shah 2004). This reliability assessment addressed the long-term creep behavior using a large amount of creep test data (Brinkman *et al*., 1991) on Inconel 718 and limited accelerated benchmark creep test data generated at NASA GRC (Bowman 2001). However, the subject Stirling radioisotope power system is required to perform reliably under any possible random event to ensure minimum risk. Under rare conditions it may happen that the temperature in the heater head could rise above designed operating limit due to a faulty sensor or control. Additionally, since these missions take place in deep space and are monitored from earth, it might take time to correct the system and bring it back to design operation through the health monitoring/correction system. Such small-duration thermal excursions during the life of the heater head could affect its durability significantly. The durability of the heater head under such events depends on the time in to the mission at which an excursion occurs, its magnitude and its duration. The excursion parameters are random in nature and should be treated in a probabilistic sense. A deterministic model to capture the mechanics and physics involved was developed and reported by Shah *et al* (2004).

The present paper encompasses the random nature of the parameters related to the thermal excursions during the entire mission in the reliability assessment of the heater head. Effect of these parameters on life of the heater head for a desired reliability has been described. Importance of the reliability of sensors, controls and health monitoring system especially during the later part of the mission has been highlighted.

II. Reliability Assessment of Heater Head

Reliability-based analysis of the heater head using the creep durability model developed and the large creep rupture database generated by Oak Ridge National Laboratory (ORNL) was performed (Shah *et al*, 2004) and brief description of the methodology used and its results are described herein since it forms a basis for the content of this paper.

The material used for the ORNL tests and that to be used in the current heater head have main differences in their heat treatments, thickness (heater head wall thickness being only 5% of the thickness of the ORNL material). However, the methodology used captured the differences and accounted for their effect on creep behavior and associated uncertainties. Heater head material, referred to as GRC material hereinafter, showed a mean life to be much lower than that of ORNL material since it is much thinner. However, due to controlled processing and fabrication, the GRC material shows much less scatter in life compared to the ORNL material. Hence the methodology used: (i) the ORNL master curve model independent of stress and temperature, eq. (1), (ii) ORNL creep rupture law, eq. (2), with the modified “heat” constant, C_h, for the GRC material, (iii) probability distribution of the ORNL material behavior, (iv) scatter quantified using GRC material test data, and (iv) factor, X developed based on nonlinear regression analysis of ORNL and GRC material to predict life of GRC material using the ORNL material data and model.

$$\varepsilon^* = \exp[\gamma(t^* - 1)](t^*)^{\delta} \tag{1}$$

where ε^* is the normalized creep strain (with respect to creep strain at the onset of tertiary creep), t^* is the normalized time (with respect to time at the onset of tertiary strain), and γ and δ are constants quantified from test data.

$$\log(t_r) = C_h + C_1 \log\sigma + C_2 (\log\sigma)^2 + C_3 (\log\sigma)^3 + C_4 T (\log\sigma) \tag{2}$$

where, C_h, C_1, C_2, C_3, *and* C_4 are the constants determined from the ORNL data (for Inconel 718, C_h = 162.319, C_1 = -193.662, C_2 = 88.117, C_3 = -12.807, and C_4 = -0.01052), t_r = rupture life (h), σ = stress (MPa), and T = temperature (K)

The shift in time-to-rupture due to factor, X, figure 1, reflects the combined effects of thin specimens, chemistry, and grain size (heat treatment). The rupture life is downscaled to give an estimation of the time to the onset of the tertiary creep. The scale factor for the time (t_{ss}) to reach tertiary creep for the ORNL material is approximately 70% of the rupture life (t_r), whereas that for the GRC material has been observed in the range 40 to 60%. Although the percentage of life for onset of tertiary creep for ORNL and GRC material are different, we use 70% of rupture time to define the deterministic design life, t_f.

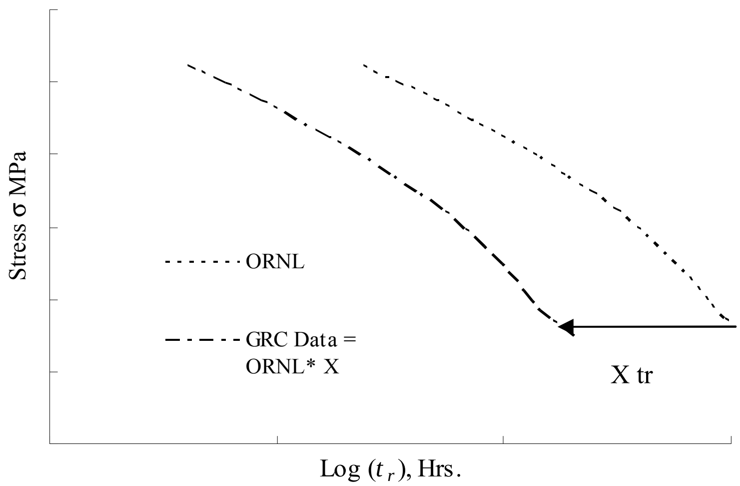

Figure 1. Comparison between ORNL and GRC creep rupture data.

The uncertainties in the material behavior, geometry, and loads, etc. were included to perform probabilistic creep and rupture durability analyses using fast probability integration and/or a Monte-Carlo simulation as appropriate. The method of most-likelihood-event (MLE) combined with the least squares approach has been used to quantify the uncertainties in the material behavior (constant, C_h in eq. (2)). Since the rupture life shows lognormal distribution, obviously the constant C_h in eq. (2) also shows a normal distribution. Uncertainties in the heater head thickness was considered such that the bounds on the tolerances relate to the ±3 standard deviations. The uncertainty in the pressure corresponds to the maximum permissible variation of 10% being ±3 standard deviations. In a similar manner, the maximum variation of 10 °C in temperature corresponds to ±3 standard deviations. Probability distribution of the creep rupture design life was computed and probabilistic factors were computed using an engineering approach for 99.9% and 99.99% reliability which were used in the reliability-based life analysis under random thermal spike excursions. The life for 99.99% probability of survival (PoS) without the effect of thermal spike excursions was computed as 116000 hours (13.25 yrs.). Also, the sensitivity (defined as the level of significance to the reliability, on a scale of 0 to 1, 0 being the least and 1 being the most) of life to the design variable uncertainties showed that scatter in the material properties (creep behavior) is the most sensitive.

III. Heater Head Life Reliability Analysis under Random Thermal Spike Excursions

A. Mathematical formulation

Thermal excursions during the life of the heater head could affect its durability significantly. Heater head durability under such events depends on the time at which an excursion occurs, its magnitude and its duration. These excursion parameters are random in nature and should be treated in a probabilistic sense. Probabilistic analysis of random thermal spike excursion reported herein is a combination of reliability factors developed in the probabilistic analysis described in the previous section (Shah 2004) and Monte-Carlo simulation of life under random thermal excursions. The probabilistic analysis first requires a deterministic model to capture the mechanics and physics involved. Although the formulation developed to perform the life analysis under a thermal excursion was reported by Shah 2004, the following paragraphs describe it for the completeness of this paper. The ORNL master curve approach, eq. (1) has been used to assess the creep strain. Refer to Brinkman et al., 1991 for more details on the master curve. Rupture lives for given stresses and temperatures were calculated from eq. (2) and adjusted to represent the GRC material.

The on-set of tertiary creep time, t_{ss} is represented by a simple power law expression

$$t_{ss} = At_r^{\beta} \tag{3}$$

with values of A and β being 0.442 and 1.04, respectively. Note that the equation is nearly linear and at t_r = 100,000-hr, t_{ss} = 70,000-hr. Also, for the ORNL material, the steady state creep rate leading up to the onset of tertiary creep, $\dot{\varepsilon}_{ss}$, may be represented in the following form

$$\dot{\varepsilon}_{ss} = Bt_r^{-\alpha} \tag{4}$$

where B = 2.142 and α = 1.151. The concept of a "master curve" was used to develop the following creep-strain relationship:

$$\varepsilon^{*} = \exp[\gamma(t^{*} - 1)](t^{*})^{\delta} \tag{5}$$

where ε^{*}(= $\varepsilon/\varepsilon_{ss}$) and t^{*}(= t/t_{ss}) are normalized creep strain and normalized time, respectively; and γ = 1.75, δ = 0.2.

Using eqs. (3) through (5) and the chain rule for derivatives, the relationship between the rate of creep strain and creep strain can be expressed by the following equation:

$$\dot{\varepsilon} = \gamma\varepsilon_{ss}t_{ss}^{-1}\left(1 + \frac{\delta}{\gamma}\frac{1}{t^{*}}\right)\exp[\gamma(t^{*} - 1)](t^{*})^{\delta} \tag{6}$$

Assuming that a "design failure time" constitutes the *p-th fraction* of a tertiary creep time $t^{*} = p$, we obtained

$$\dot{\varepsilon} = a\left(0.2 + ct_r^{\alpha+\beta}\right)t_r^{-\beta} \tag{7}$$

where for p = 0.7.

$$\begin{aligned} a &= \gamma\left(1 + \frac{\delta}{\gamma}\frac{1}{t^{*}}\right)\exp[\gamma(p - 1)](p)^{\delta} = 1.12 \\ c &= A * B = 0.95, \quad A = 0.442 \end{aligned} \tag{8}$$

The constant steady state creep rate is assumed to be a function only of two independent external parameters, stress and temperature, which in turn influences the mechanical behavior of the structure. This allows us to write the creep rate in the following form

$$\frac{d\varepsilon}{dt} = \phi(\sigma, T) \tag{9}$$

Suppose that at constant stress, the temperature suddenly changes from T to $T_1 = T + \Delta T_0$. Thus, the material will respond with a different creep rate in accordance with eq. (9):

$$\frac{d\varepsilon_{T_1}}{dt} = \phi(\sigma, T + \Delta T) \approx \phi(\sigma, T) + \frac{\partial\phi}{\partial T}\Delta T$$

Integrating, one obtains:

$$t_r = \int_{\varepsilon_0}^{\varepsilon_r} \frac{1 - \phi^{-1}\dfrac{\partial\phi}{\partial T}\Delta T}{\phi(\sigma, T)} d\varepsilon \tag{10}$$

where ε_r is the maximum creep strain accepted for design and ε_o is the creep strain when the temperature change occurred. This equation may be used to evaluate maximum allowable time for creep in the case when temperature increases and stays constant afterwards, figure 2 (solid lines). In this case, ΔT=*const.* If ΔT is not small, additional considerations are needed for model development.

If the stress is dependent on temperature, then

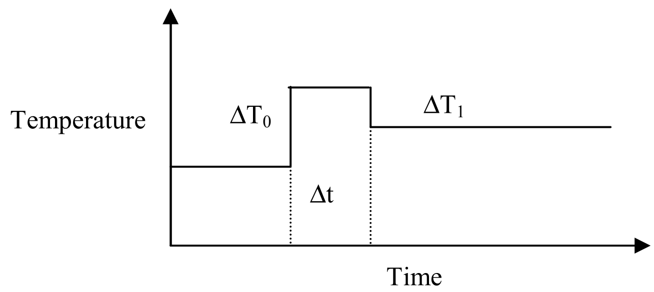

Figure 2. Thermal excursion.

$$\phi(\sigma(T+\Delta T), T+\Delta T) = \phi(\sigma, T) + \left(\frac{\partial \phi}{\partial \sigma}\frac{\partial \sigma}{\partial T} + \frac{\partial \phi}{\partial T}\right)\Delta T \tag{11}$$

eq. (10) can be also rewritten in the form:

$$t_r = (t_r)_T - \Delta T_0 \int_{\varepsilon_o^+}^{\varepsilon_r} \phi^{-2}(\sigma, T)\frac{\partial \phi(\sigma, T)}{\partial T} d\varepsilon \tag{12}$$

The same procedure repeated for temperature drops, $\Delta T < 0$, results in the following equation:

$$t_r = (t_r)_T + \Delta T_1 \int_{\varepsilon_1^-}^{\varepsilon_r} \phi^{-2}(\sigma, T)\frac{\partial \phi(\sigma, T)}{\partial T} d\varepsilon \tag{13}$$

Combining these equations gives the rupture time for a "thermal step function" when $\Delta T_0 = \Delta T_1 = \Delta T$ is given by:

$$t_r = (t_r)_T - \Delta T \int_{\varepsilon_0^+}^{\varepsilon_1^-} \phi^{-2}(\sigma, T)\frac{\partial \phi(\sigma, T)}{\partial T} d\varepsilon \tag{14}$$

If the duration of the temperature increment is small, the approximate rupture time is found to be:

$$t_r = (t_r)_T - \phi^{-1}(\sigma, T)\frac{\partial \phi(\sigma, T)}{\partial T}\Delta T \Delta t \tag{15}$$

In the case of multiple temperature changes T_k, eqs. (12) and (13) can be generalized as follows:

$$t_r = (t_r)_T - \sum_{k=1}^{M} \Delta T_k^+ \int_{\varepsilon_K^+}^{\varepsilon_r} \phi^{-2}(\sigma, T)\frac{\partial \phi(\sigma, T)}{\partial T} d\varepsilon \tag{16a}$$

$$t_r = (t_r)_T + \sum_{k=1}^{M} \Delta T_k^- \int_{\varepsilon_K^-}^{\varepsilon_r} \phi^{-2}(\sigma, T)\frac{\partial \phi(\sigma, T)}{\partial T} d\varepsilon \tag{16b}$$

The heater head durability methodology for thermal excursions assumes that the strain rate remains constant during the secondary creep zone and the material recovers the original strain rate during the post excursion time. Using the above formulation the heater head life under thermal spike magnitudes of 10, 20, and 30 °C above an operational temperature of 650 °C was calculated using Monte-Carlo simulations. The reliability factors developed from the probabilistic analysis accounting for uncertainties in the material properties, temperature, pressure and thickness were applied to the life computed in each Monte-Carlo sample. A total of 10000 samples have been used in the analysis to compute the reliability of heater head life due to thermal spike excursions.

B. Random life analysis

As discussed in the earlier sections, the time at which the thermal excursion occurs, the duration of the excursion and the thermal spike magnitudes have been considered random in the analysis using lognormal, Weibull and normal distributions respectively. The random spikes have been modeled using probability distributions and not as random process since it is expected that such events could occur, at the most, one to three times during the mission only. In fact the SRG design does not want to permit even one such event. However, the possibility of thermal excursion may not be ruled out and therefore such an evaluation is necessary. The standard deviation of 0.1 year has been assumed for the time at which excursion occurs and lognormal distribution suggest that most of the probability mass is around the mean value. In a similar manner the Weibull distribution is justified for the duration of spike for which a standard deviation of 10% has been used in the analysis. Additionally, a standard deviation of 2 °C has been assumed for the thermal spike magnitude.

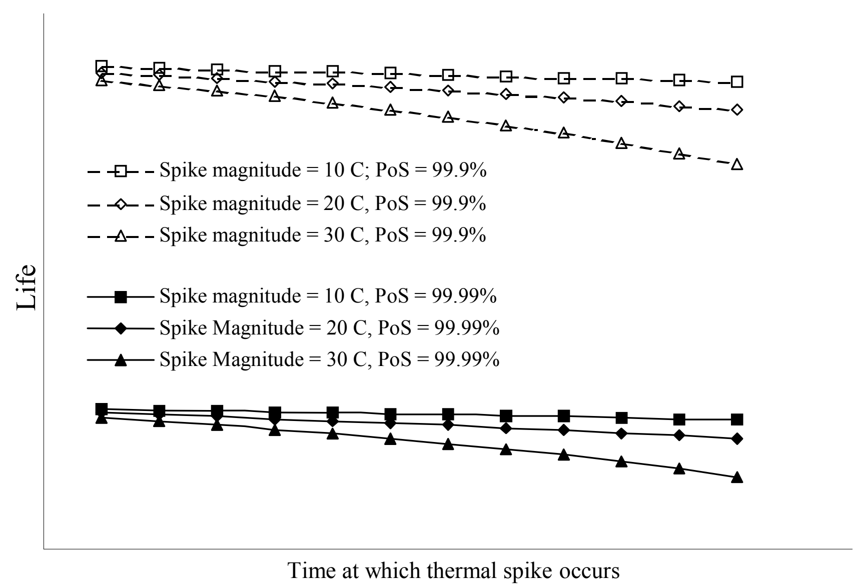

Figure 3. Effect of time of thermal spike occurrence on heater head life for spike duration 180 days.

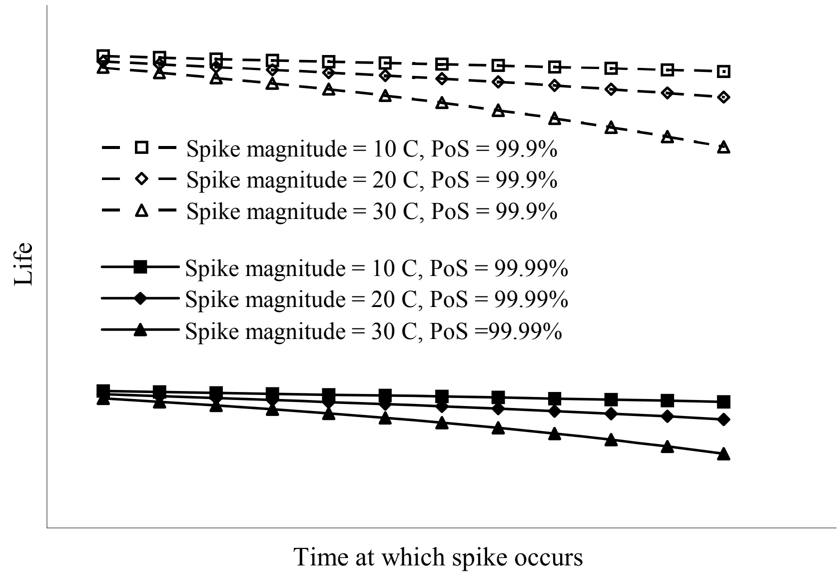

Figure 4. Effect of time of thermal spike occurrence on heater head life for spike duration of 30 days.

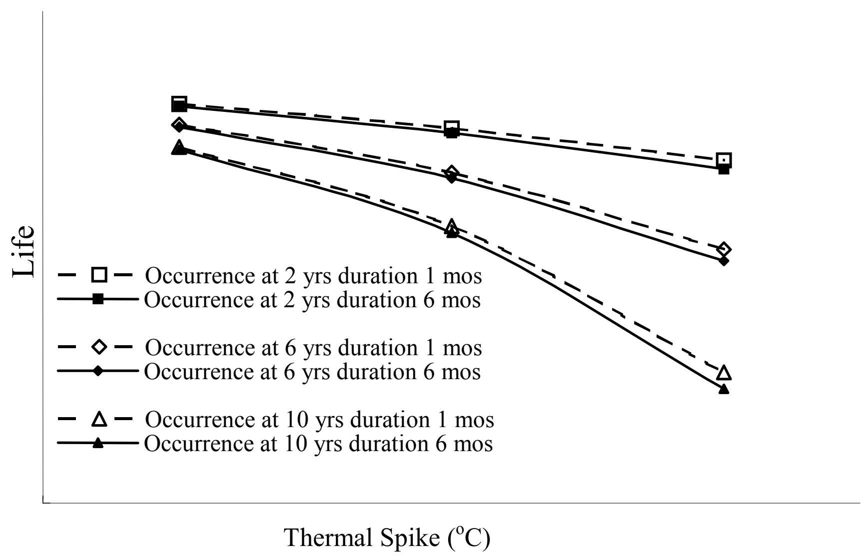

Figure 5. Effect of thermal spike magnitude on heater head life for 99.99% Probability of Survival.

The Monte-Carlo simulation results combined with the probabilistic factors that include the effect of uncertainties due to material properties, thickness of heater head wall, pressure and temperature have been computed. The results are represented showing the effect of the time at which thermal spike occurs, thermal spike duration and thermal spike magnitude on the reliable life. As mentioned earlier the thermal spike durations of 30, 60, and 180 days and magnitudes of 10, 20, and 30 °C over-operational design temperatures have been considered in the analysis. It is intuitively reasonable to expect that thermal spike duration would not have impact on the reliable life mainly due to the fact that the durations analyzed are a small percentage of the mission duration and the assumption that the material resumes creep at the strain rate same as prior to the occurrence of thermal spike. Results also show that the effect of thermal spike duration on the reliable life is negligible, and therefore have not been documented here for brevity. Figure 3 shows the effect of the time at which the thermal spike occurs during the mission. It clearly shows

that the reliable life decreases as the time at which the spike occurs increases toward the later part of the mission. Furthermore, the percentage of reduction in life is higher for larger thermal spike magnitudes. The life for 99.99% reliability with mean 10, 20, and 30 °C spike magnitudes with 180 days of duration is respectively 12.88, 12.46, and 11.62 years as opposed to 13.25 years with no thermal excursion. Thus, a 20 °C difference in the thermal spike magnitude lasting for six months reduces the reliable life by one year and three months. Similarly the life for 99.90% reliability with mean 10, 20, and 30 °C spike magnitude with 180 days of duration is, respectively, 20.46, 19.84, and 18.63 years as opposed to 21.5 years with no thermal excursion. As shown in figure 4 the life for 99.99% reliability with mean 10, 20, and 30 °C spike magnitude with 30 days of duration is respectively 12.90, 12.49, and 11.70 years as opposed to 13.25 years with no thermal excursion. Similarly the life for 99.90% reliability with mean 10, 20, and 30 °C spike magnitude with 30 days of duration is respectively 20.48, 19.89, and 18.75 years as opposed to 21.5 years with no thermal excursion. This means that the reliability requirement of the sensors or controls or the health monitoring system must be very high at later stages of the mission since the thermal spike occurrences could reduce life rapidly during the later part of the mission. This is a very important conclusion of the study and therefore Stirling convertor design process must ensure this requirement is met in order to increase the reliability of the heater head durability under possible, but rare, thermal excursion. It is seen in figure 5 that the change in life due to spike duration from 30 days to 180 days is insignificant compare to the mission span. Figures 5 shows the variation in life versus thermal spike magnitude with 1 and 6 months spike duration respectively for 99.99% PoS and time of spike occurrence at 2, 6, and 10 years. It clearly shows that the reduction in life increases nonlinearly with the thermal spike magnitude. As the thermal spike magnitude increases the life reduces rapidly since the creep rate is an exponential function of the time. Although this study is based on the assumptions of the uncertainties in magnitudes of the random variables related to the thermal excursion event parameters, it would be appropriate to obtain more realistic values from the system integrators, sensor and control designers or the engineers involved in the design of those components that could become a cause for excursions.

IV. Summary

A methodology to simulate uncertainties in the Stirling Convertor heater head design variables and the random thermal spike parameters has been developed to quantify the reliability of heater head life. The methodology has been applied and heater head life for 99.9% and 99.99% probability of survival (PoS) is quantified. The results show that the duration of a thermal spike of up to 6 months has insignificant impact on the life. However, the time at which the spike occurs and the magnitude of the thermal spike has significant effect on the reliable life. Also, the thermal spike magnitude has higher impact of reducing the reliable life than the time at which thermal spike occurs. The life of the heater head for 99.99% PoS reduces from 13.25 to 11.62 yrs. (a 12.3% loss in mission life) if it experiences a thermal spike of mean magnitude of 30 °C occurring around the 10th year in the mission and that it lasts for 6 mos. Generally, as the mission progresses, the reliability of the components and the system reduces which could increase the chance of a thermal spike occurrence. Considering this fact and its impact on the critical heater head, life reliability, it is important to emphasize to designers of sensors, controls, health monitoring systems or any components that could be a cause of a thermal spike that a very high reliability is required to assure a reliable and durable performance of the heater head for a successful mission.

References

Bowman, R.R., "Long-Term Creep Assessment of a Thin-Walled Inconel 718 Stirling Power-Convertor Heater Head," Paper CT-33, in *Proceedings of the 36th Intersociety Energy Conversion Engineering Conference*, edited by D.M. Allen et al., IECEC Conference Proceedings, vol. 1, American Society of Mechanical Engineers, New York, 2001, pp. 435-440.

Halford, G., Shah A., *et al* "Structural Analyses of Stirling Power-Convertor Heater Head for Long-Term Reliability, Durability, and Performance," in Proceedings of *Space Technology and Applications International Forum (STAIF–2002),* sponsored by the American Institute of Aeronautics and Astronautics, Albuquerque, New Mexico, February 3-7, 2002, pp. 880-887.

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13. ABSTRACT ***(Maximum 200 words)***

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